PATHS TO FUSION POWER

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Energy Options for the Future
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TOPICS

- What is Fusion?
- Why Fusion?
- Technical Approaches
- Issues
- Progress and Projections

What is Fusion?

Fusion is the process that generates light and heat in the Sun and other stars

It is most easily achieved on earth by combining the heavy isotopes of hydrogen (deuterium and tritium) to form isotopes of helium

WHY FUSION

Fusion fuel is abundant, widely available and low cost

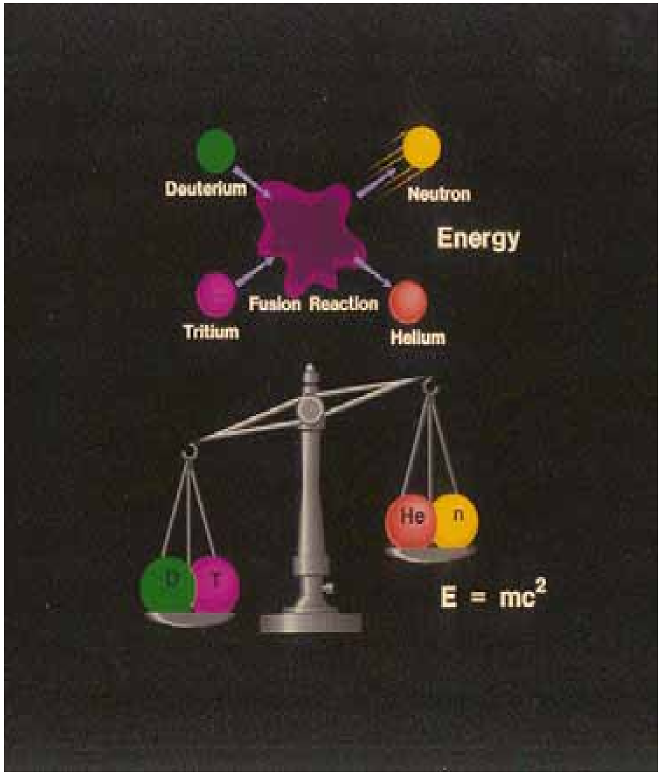
The fusion reaction itself produces no radioactive waste; activated structure has relatively low hazard potential and relatively short half-life

While the primary goal of fusion development is central station electric power plants, fusion plants may also be useful for

- Hydrogen production
- Desalination of water
- Production of fuel for fission reactors
- Deactivation of fission reactor waste

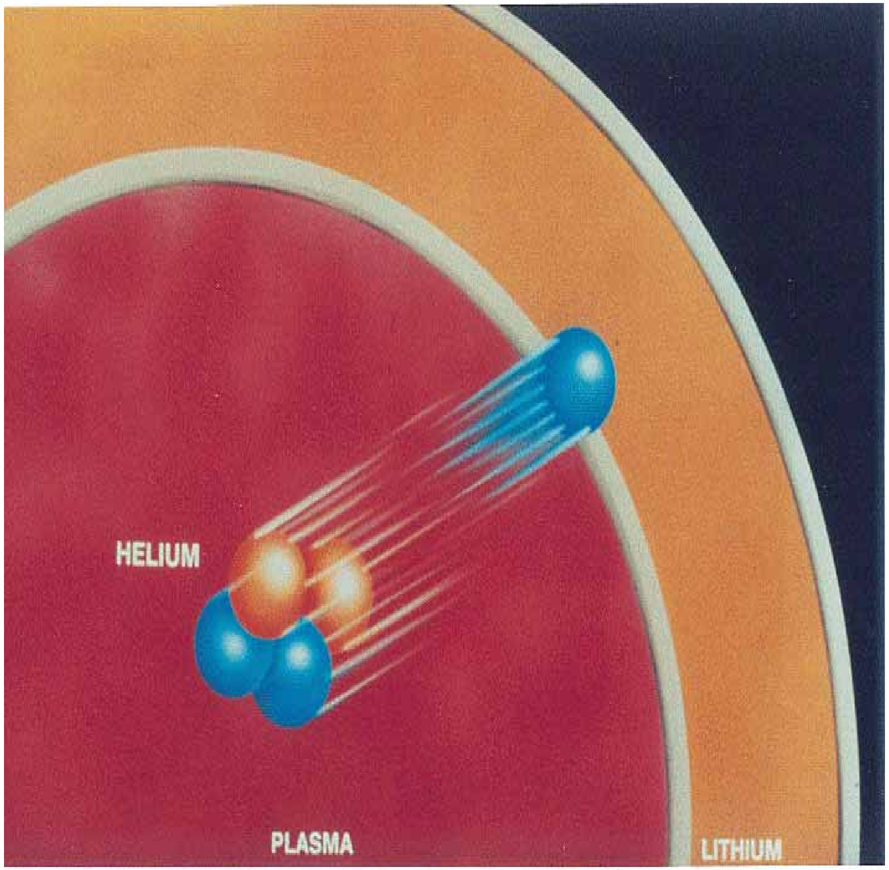
FUSION REACTION

Deuterium and Tritium fuse at high energy (10 KeV), producing helium and an energetic (14 MeV) neutron



Mass is converted to energy according to Einstein's formula

FUSION POWER PLANT

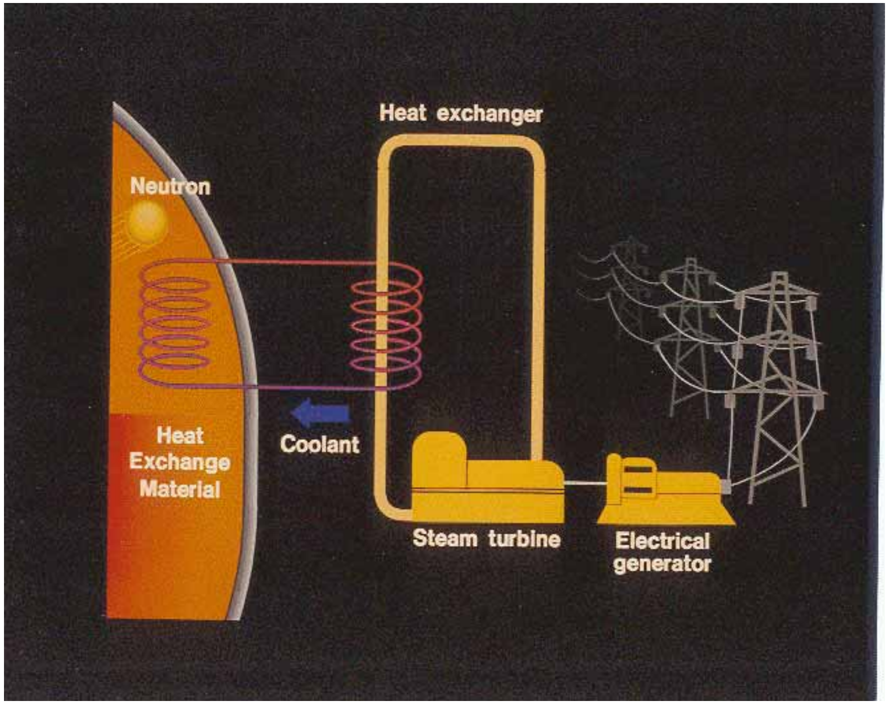


The helium nucleus gives up its energy to the plasma, thus sustaining its temperature

The energetic neutron is captured in a moderator blanket, heating it and reacting with lithium to produce tritium fuel

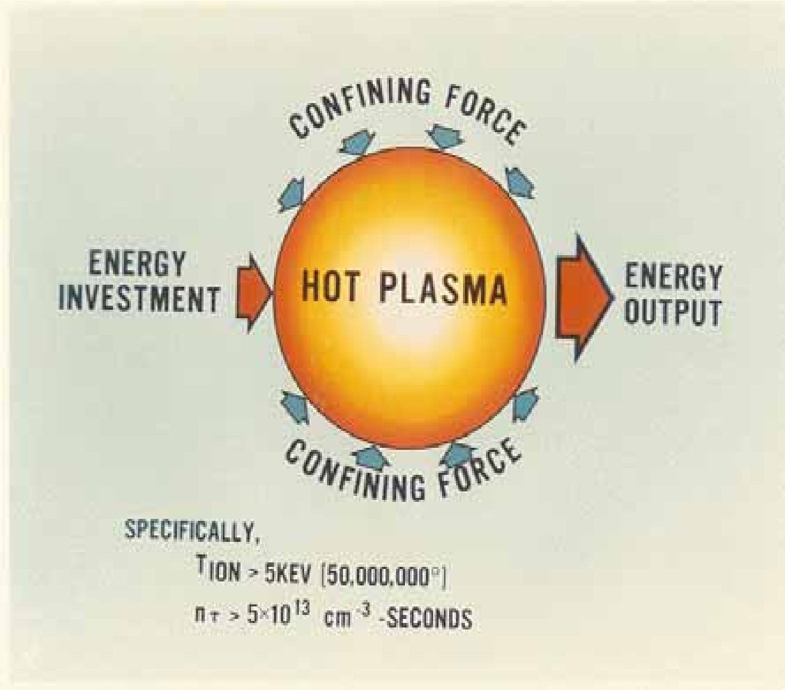
FUSION POWER PLANT

A conventional heat exchange system removes heat from the moderator blanket



Heat is converted to electricity by a conventional power conversion system

TECHNICAL APPROACHES



Fusion fuel is heated, creating hot "plasma."

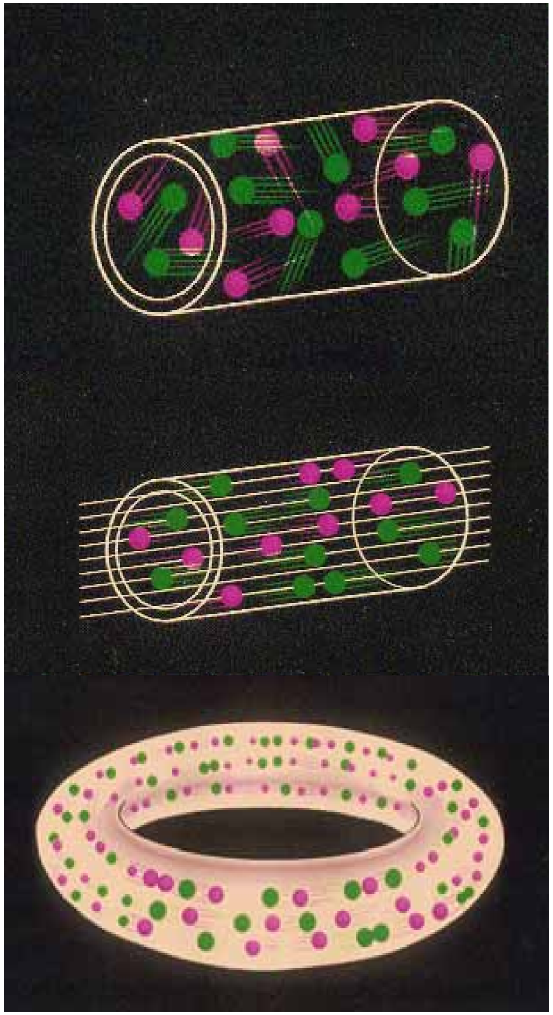
It must then be confined long enough to release net energy.

There are two main technical approach categories:

Magnetic Confinement: At low, sub-atmospheric density, the fuel must be confined for many seconds.

Inertial Confinement: At high, greater than solid density, the fuel must be confined for small fractions of a second

MAGNETIC CONFINEMENT

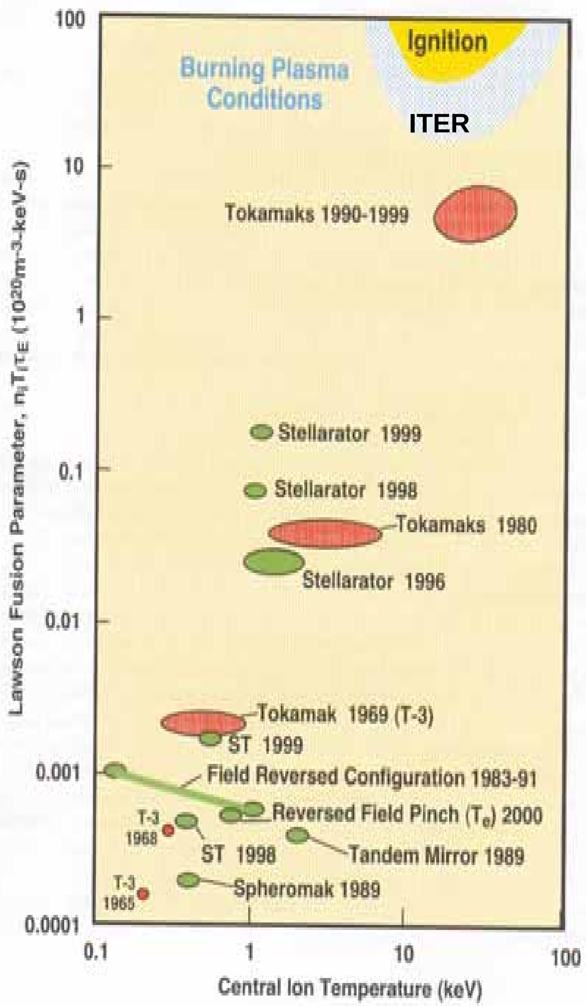


Fast-moving particles in a simple container would quickly strike the walls, giving up their energy before fusing

Magnetic fields exert forces that can inhibit and direct the motion of the particles

Magnetic fields can be fashioned into complex configurations sometimes called magnetic bottles

MAGNETIC CONFIGURATIONS



There are many magnetic configurations, but the most successful to date has been the tokamak configuration

ITER, a tokamak engineering test reactor, is aimed at achieving burning plasma conditions near or at ignition in the latter half of the next decade

ITER ENGINEERING TEST REACTOR

A joint venture of the European Union, Japan, Russia, United States, China and Korea, to be sited in either France or Japan

Initiate construction in 2006

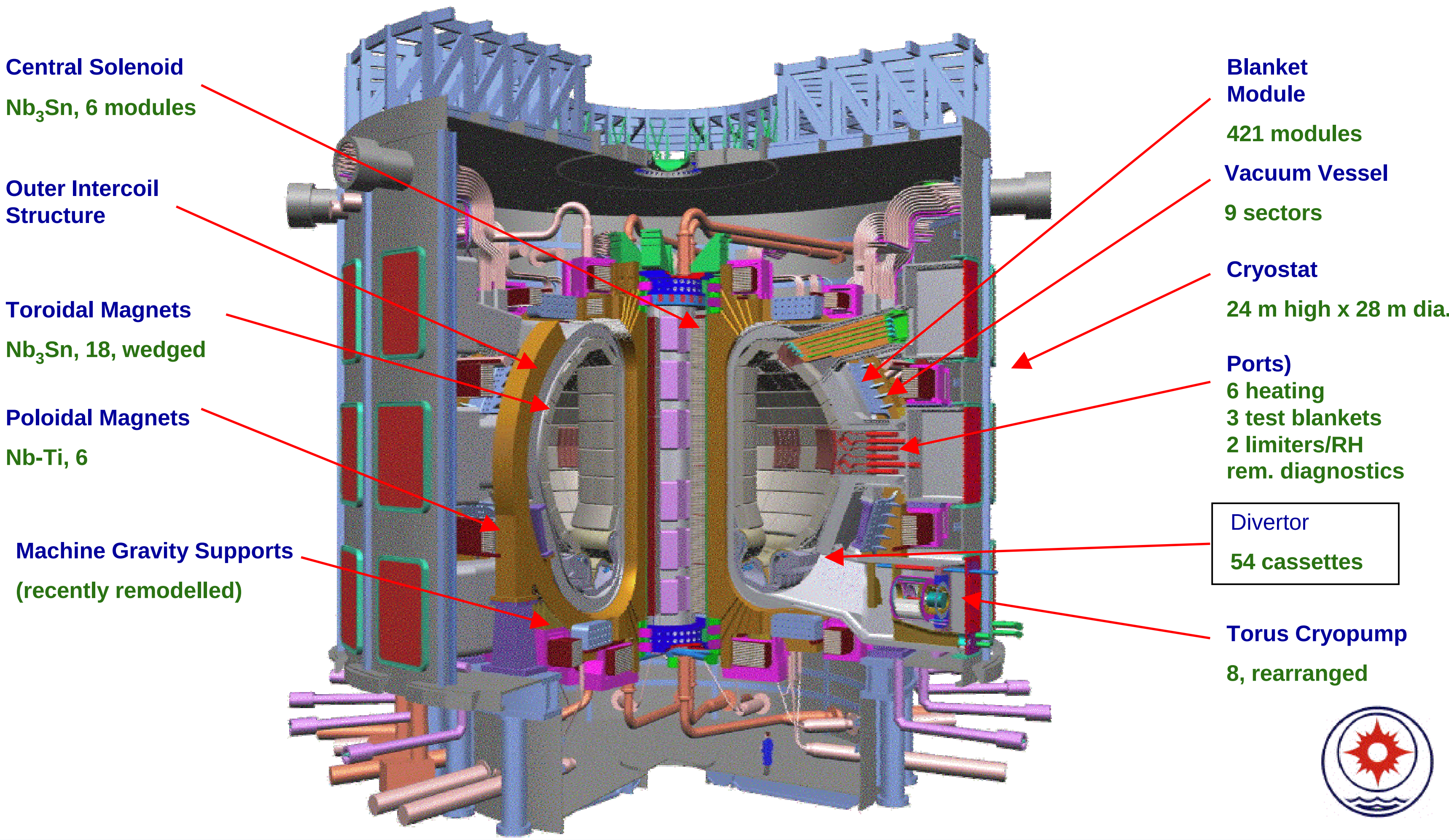
Begin operation in 2014

Design Specifications:

- **Fusion Power: 500-700 Mw (thermal)**
- **Burn time: 300 s (upgradable to steady state)**
- **Plasma volume: 837 cubic meters**
- **Plasma radius: 2 meters**
- **Machine major radius: 6.2 meters**
- **Magnetic Field: 5.3 Tesla**

ITER

INTERNATIONAL THERMONUCLEAR EXPERIMENTAL REACTOR



FACILITIES - MAGNETIC

Primary efforts are in Europe, Japan and U.S.

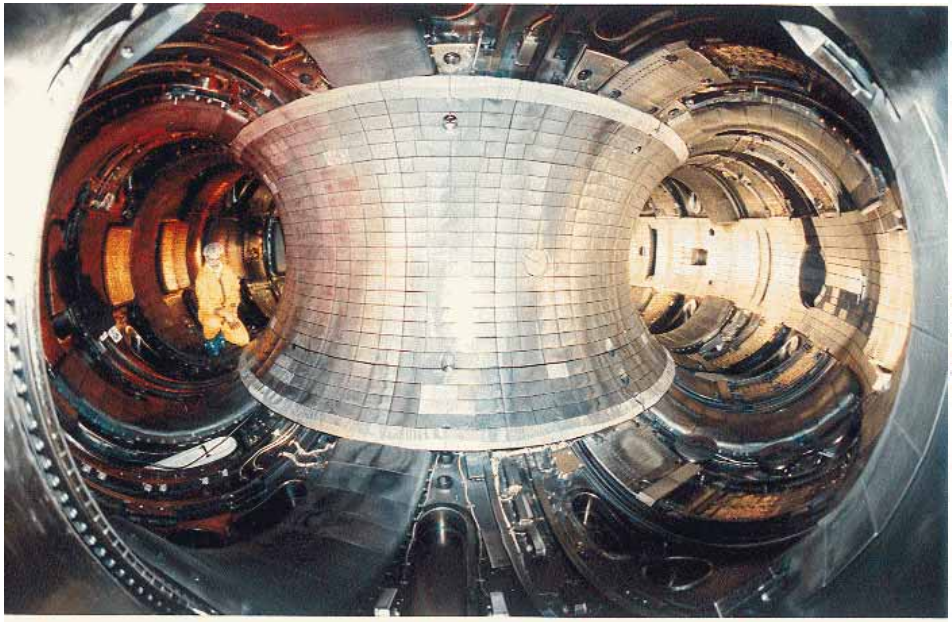
Major U.S. sites are at Princeton Plasma Physics Laboratory, General Atomics, MIT and Oak Ridge National Laboratory

JET tokamak in England and TFTR at Princeton produced around 10 Mw of fusion power for about one second during 1990s

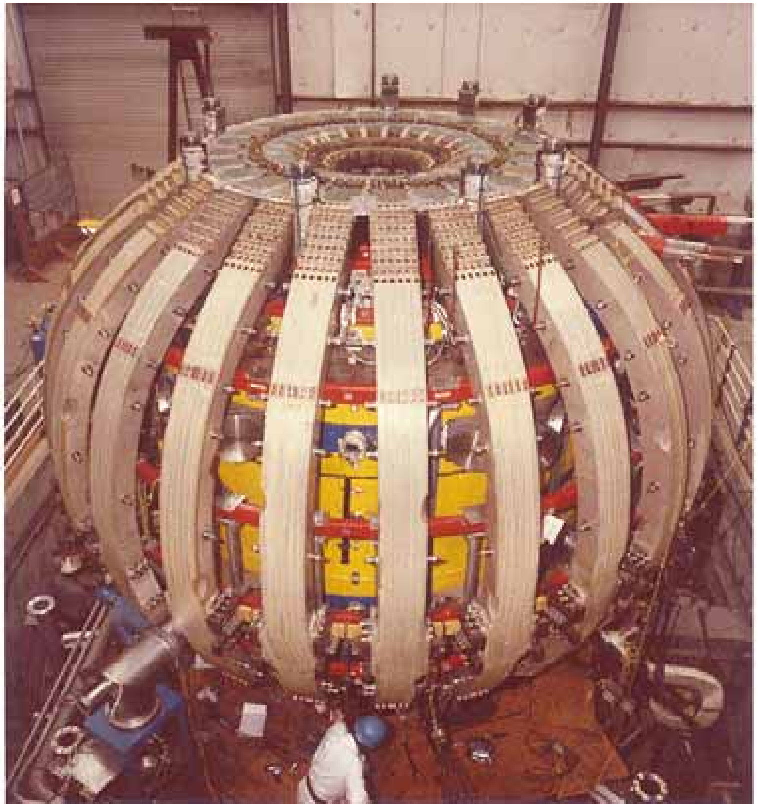
JT-60 in Japan, which does not use tritium, produced equivalent conditions in deuterium.

DIII-D, at General Atomics, and Alcator C-Mod, at MIT are currently largest tokamaks operation in U.S.

FACILITIES - MAGNETIC

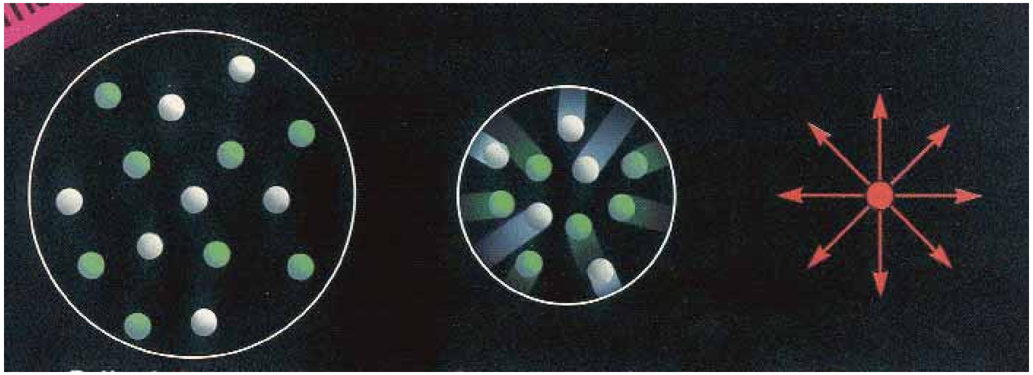


Interior of TFTR vacuum chamber



DIII-D at General Atomics

INERTIAL CONFINEMENT



A capsule containing deuterium and tritium is irradiated by x-ray, laser or particle beams,

compressing and heating the fuel to ignition

INERTIAL FUSION “DRIVERS”

Capsules containing fusion fuel may be “driven” by various energy sources

Four drivers are currently under development

- Krypton Fluoride Lasers
- Diode-pumped solid state lasers
- Heavy-ion accelerators
- Z-pinch X-rays

NATIONAL IGNITION FACILITY
NIF

Laser-based National Ignition Facility (NIF), under construction and in partial operation at LLNL, is aimed at achieving ignition within 10-15 years

FACILITIES - INERTIAL

Primary efforts are in the U.S., France and Japan.

Major U.S. sites are at:

Lawrence Berkeley National Laboratory: Heavy Ions

Lawrence Livermore Nat'l Lab: Solid State Lasers

U.S. Naval Research Laboratory - KrF Lasers

Sandia National Laboratories: Z-Pinch X-rays

University of Rochester: Capsule irradiations

General Atomics - Capsule fabrication

FACILITIES - INERTIAL

Heavy-ion 4-beam accelerator at LBNL

Electra KrF laser at NRL

ISSUES

For Magnetic Fusion, the primary issues are optimizing the configuration for effective confinement of the fuel and extending from pulsed to steady-state operation.

For Inertial Fusion, the primary issues are optimizing the techniques for compressing the fuel in a stable manner and extending from single pulse to repetitive pulse operation.

For both, identifying materials that provide long life and low induced radioactivity in a harsh, neutron-rich environment.

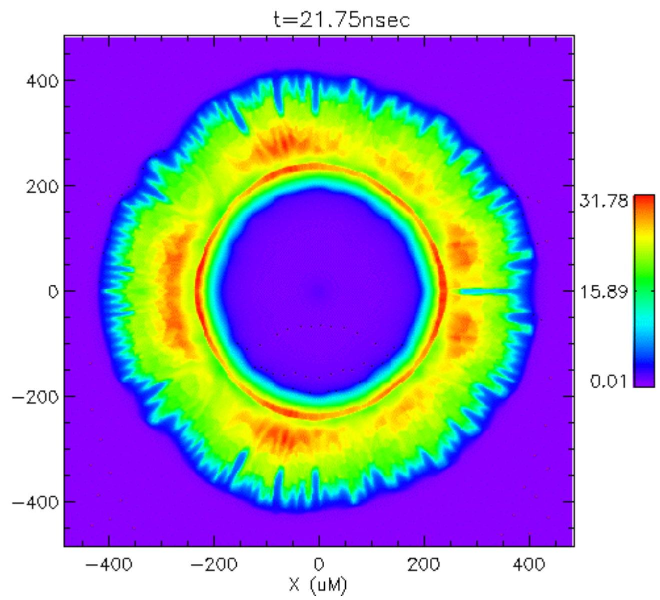
For both, optimizing the total system to reduce projected development and capital cost and demonstrating methods for ensuring reliability and cost-effective maintenance.

Progress

Progress has been systematic in both magnetic and inertial fusion.

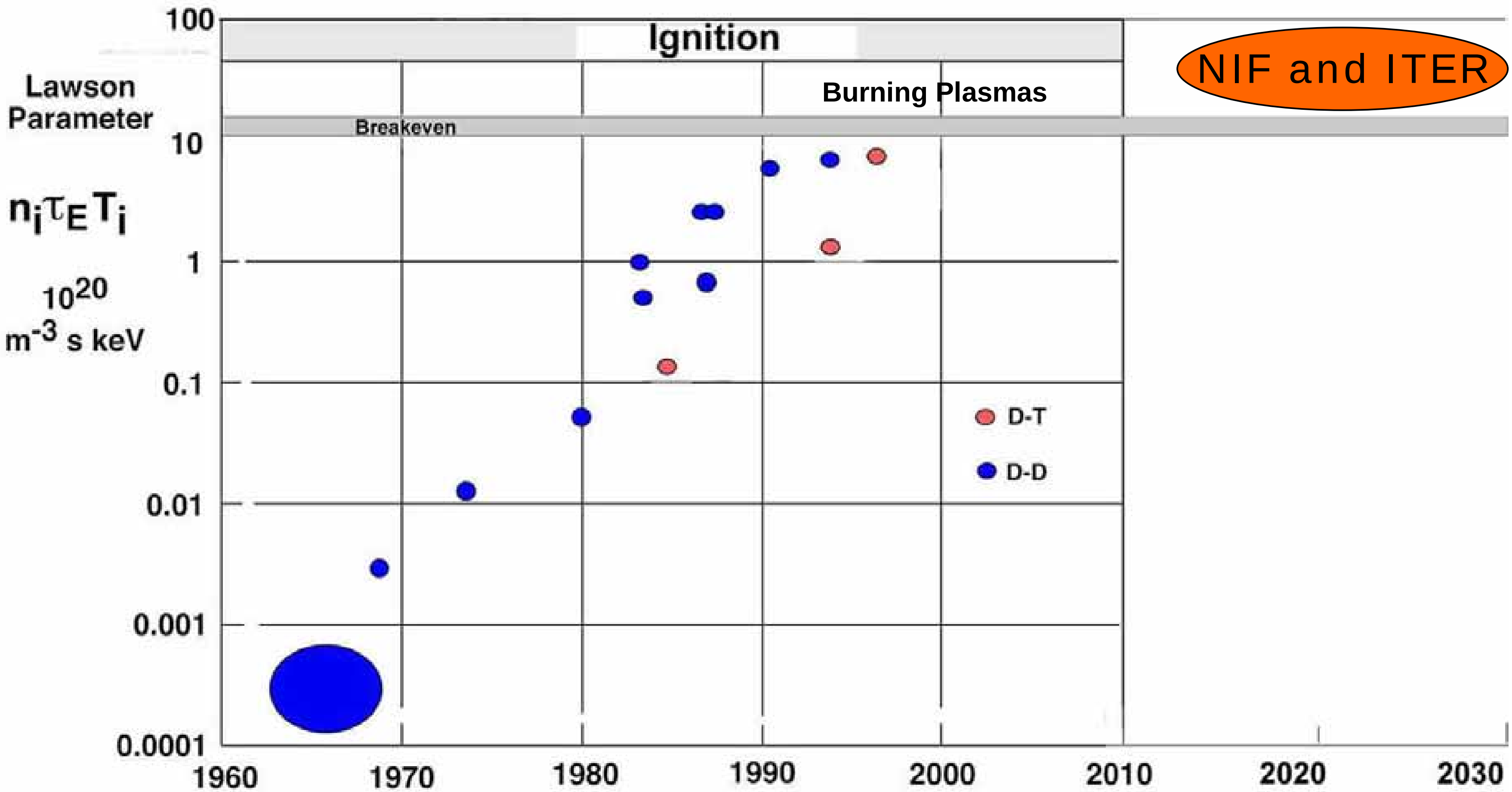
The pace of progress has been slowed by and failure to make timely commitments to new, advanced facilities

Also, recent advances in computers and scientific computation are resulting in accelerated progress



Simulated pellet is about 500 psec from ignition. There are 2048 grid points about the half sphere (zero to pi) and 408 grid points in the radial direction

Fusion Progress and Projections

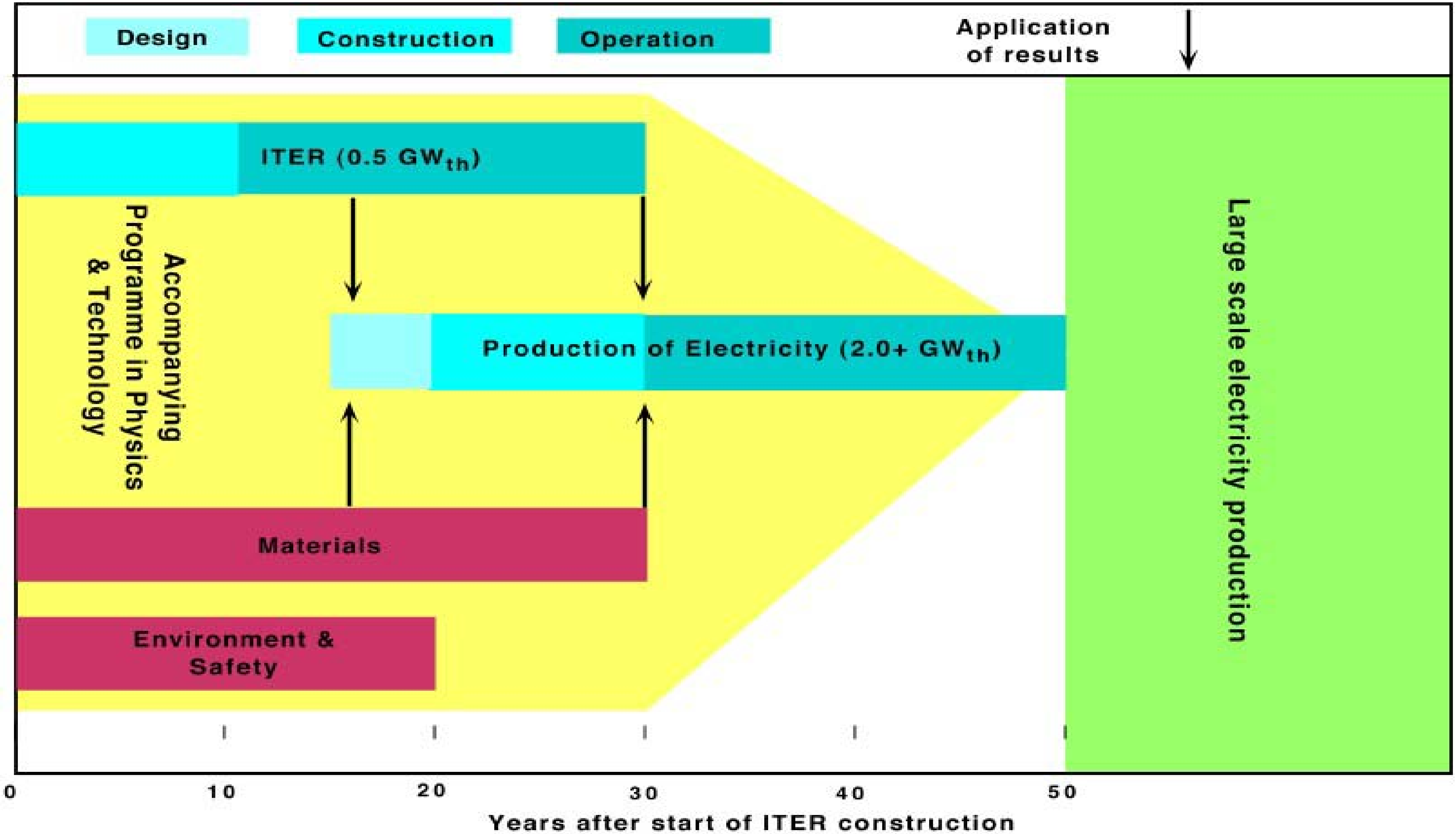


Beyond NIF and ITER

- A number of projections to power plant operation have been made, though there is no official government timetable for fusion
- There are large uncertainties in these projections due to technical unknowns and to lack of firm funding commitments
- The projections range from 15 to 50 years, with a mean around 30-35 years

ITER Project Office Magnetic Fusion Roadmap

December 2003



The Path to Develop Laser Fusion Energy USNRL - 2003

Phase I:
1999-2005

Basic laser fusion technology

- Krypton fluoride laser
- Diode-pumped solid-state laser
- Target fabrication and injection
- Chamber materials and optics

Target design & physics

- 2D/3D simulations
- 1-30 kJ laser-target exp.

Phase II
2006-2014

Develop full-size components

- Power plant laser beamline
- Target fab/injection facility
- Power plant design

Ignition physics validation

- MJ pellet implosions (NIF)
- Calibrated 3D simulations

Phase III
ETF operating
~2020

Engineering Test Facility (ETF)

- 2-3 MJ laser-driven implosions @ 5-10 Hz
- Optimize chamber materials & components
- Generate net electricity from fusion

FUSION POLICY

Excerpts from Fusion Power Associates Board of Directors Policy Statement on Fusion Energy Development
http://fusionpower.org

"Innovative ideas that reduce costs or accelerate knowledge should be expeditiously pursued in all aspects of the fusion program."

"Engineering sciences, technology development, systems analysis and plasma sciences should all be considered essential elements in a balanced fusion effort."

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